Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

# CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

**Mining Research Laboratories**

**Laboratoires de recherche minière**

Canada

# WHY PERFORM LABORATORY EXPLOSION TESTS?

K.J. Mintz

MRL 91-061(TR)

October 1991

This document is an unedited informal report prepared and primarily for internal use. It does not represent the formal opinion of the division or the Canada Centre for Mineral and Energy Technology (CANMET)

Ce document est un rapport [illegible] préparé et rédigé principalement pour [illegible] et ne représente nullement l'opinion officielle de la division ou du Centre canadien de la technologie des minéraux et de l'énergie (CANMET)

Pr.14.67.01.40.3

MICROMEDIA

13 pp

92-02036/

# WHY PERFORM LABORATORY EXPLOSION TESTS?

by

K.J. Mintz*

## ABSTRACT

Many people question the need for laboratory explosion tests, preferring instead field trials in actual mines. However, field trials and laboratory tests should be regarded as complementary. A number of examples of useful results that have been obtained from laboratory tests will be presented: determination of relative explosibility of different ores, minimum oxygen concentration required for explosions, and effect of particle size on explosibility of pyrite.

KEYWORDS: explosions, sulphides

---

*Research Scientist, Canadian Explosive Atmospheres Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada

# WHY PERFORM LABORATORY EXPLOSION TESTS?

*K.J. Mintz*
*Canadian Explosive Atmospheres Laboratory*
*CANMET, Energy, Mines and Resources Canada*
*555 Booth St., Ottawa, Ont. K1A 0G1*

## Introduction

To carry out research in a working mine is a difficult and expensive proposition. For sulphide dust explosions, which occur (in most mines) infrequently, any results must be interpreted statistically; it can often be difficult to obtain sufficient data to make definitive statements, because of external variables.

The first research on sulphide dust explosions, published in 1928, was carried out at the U.S. Bureau of Mines and involved gallery tests[1]. It identified the cause of the explosions as being the flame from the explosive and recommended thorough wetting of the area as well as stemming and tamping of the boreholes. Permissible explosives were shown to be slightly safer than standard explosives. Parenthetically, actual mine tests at that time showed that hydrogen sulphide ($H_2S$), as well as sulphur dioxide ($SO_2$), was produced when the conditions were wet. The concept that $H_2S$ can be a problem does not seem to be accepted today by many mine people.

From 1960 - 1968, laboratory explosion tests were carried out by Montgomery in the Fuels Research Centre (part of what is now CANMET). A simple test was developed for use by mines in the Noranda area to decide whether or not a pyritic ore was hazardous[2]. It involved heating a dried ore sample to 750°C and assuming that the weight loss was directly proportional to the amount of combustible material. An 18% loss in weight or greater was considered, based on empirical laboratory tests, to indicate that the sample was explosible. No interpretation was provided. However, if these ores are considered to be composed of pyrite plus non-sulphur containing compounds, then the weight loss is primarily due to the following reaction:

$$4\ FeS_2 + 11\ O_2 \rightarrow 2\ Fe_2O_3 + 8\ SO_2 \qquad [1]$$

The calculation based on Eq. [1] shows that the 18% boundary is equivalent to 29% sulphur. The situation would be more complicated if the ore contained other sulphur-containing species.

An explosion that occurred in the Yanahara metal mine in Japan in 1964 was investigated by their national research institute. They were able to show that the dust in that mine was explosible by igniting it with an electric coil.

Although no explosion occurred, an incident occurred on Dec. 7, 1989, involving a sulphide ore, which may be of interest. The vessel *Arctic* was carrying a cargo of "zinc concentrates" from Nanisivik to Louisiana. A member of the crew entered the hold of the vessel because water was observed. He died from asphyxiation. Laboratory tests at CANMET showed

that due to surface oxidation, the zinc concentrates, particularly when wet, consumed oxygen and generated $CO_2$ at a rate sufficiently rapid as to create an unsafe atmosphere. The zinc sulphide consumes oxygen, but does not generate $CO_2$:

$$ZnS + 2\ O_2 \rightarrow ZnSO_4 \qquad [2]$$

However, some of the small amount of pyrite present in the material reacts in the presence of water as follows:

$$FeS_2 + 3\frac{1}{2}\ O_2 + H_2O \rightarrow FeSO_4 + H_2SO_4 \qquad [3]$$

A small percentage of carbonate is also present in the concentrate; this can react as follows:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2 \qquad [4]$$

**Explosibility Measurements**

The fundamental equipment required for any explosibility test consists of a chamber, a means for dispersing the dust, an ignition source and a device for determining whether or not an explosion occurred. The simple Hartmann apparatus uses a filter paper on top of a clear plastic tube; if it breaks during the test, it is considered an explosion. A visible flame can be seen; usually a loud bang occurs as well. Care must be taken with this apparatus not to have too much explosible dust in it, otherwise, the high explosion pressure could cause the apparatus to break. Sulphide dusts do not explode in this apparatus primarily because the spark ignition used is inadequate.

The alternative Hartmann apparatus consists of a metal tube with the same type of ignition source, but with the addition of a pressure transducer to monitor the pressure history during the test. In order to make sulphide dusts explode, the tests were conducted in oxygen, rather than air. This is a rather artificial method; thus, the results from this phase of work can only be regarded as relative. The relative explosibility (RE) was defined as the maximum explosion pressure of a sample, relative to pyrite as 100. The RE of pure minerals were measured as: pyrrhotite 90, chalcopyrite 65, galena 70 and sphalerite 0. Twenty-seven ores from 10 different mines were tested; the results (Fig. 1) indicate that, in general, RE increases with sulphur content and there appears to be a cut-off at about 25% (see Fig. 1). Despite the sulphur content of sphalerite being substantially greater than the 25% cutoff, it could not be exploded. Even in the 20-L vessel with a strong ignitor using finely divided, chemically pure ZnS and an oxygen-enriched atmosphere, no explosion occurred, only some surface burning. Galena is also peculiar, exploding even though it contains only 14% sulphur. However, the reaction product in this case is $ZnSO_4$; little or no $SO_2$ is produced.

Later, a stainless-steel 20-L vessel was used. The most important improvement is the capability of using high-energy ignition sources. With them, the sulphide dusts could be ignited in ordinary air, and thus correlated directly with occurrences in the mine. A paramagnetic oxygen analyzer is used to measure the oxygen remaining after each test. In addition, the gases

produced by the explosion could be collected and analyzed by an infrared spectrometer. Typically, $SO_2$ would be several per cent of the gas mixture. The quantity of $SO_2$ measured after explosion tests on pyrite was consistent with the amount of oxygen consumed, thus providing indication that the reaction involved is the simple oxidation.

In order to determine the effect of particle size on explosibility, pure pyrite was ground, then wet-sieved. The actual mean mass-weighted particle "diameter" of each size fraction was measured using an image analyzer, because the particles were of irregular shape. Figure 2 shows that the explosion pressure increases somewhat with decreasing particle size. This is probably because a higher fraction of the pyrite particles are able to react in the explosion reaction zone due to the increased surface area. The relative quantity of $SO_2$ is fairly closely related to the relative explosion pressure.

Figure 3 shows how the rate of pressure rise, $(dP/dt)_{max}$, is related to the particle diameter. This parameter indicates the potential violence of the explosion, and how fast the explosion may travel. As the diameter decreases from 300 to about 50 $\mu$m, $(dP/dt)_{max}$ approximately doubles. However, below 50 $\mu$m, $(dP/dt)_{max}$ appears to increase very sharply. Again, this is due to the increased surface area of the particles.

The minimum explosible concentration (MEC) is useful because it indicates how much dust must be dispersed in order to have the possibility of an explosion: the greater the MEC, the safer the material. Typically, for a given material, there is some particle size above which an explosion is not possible, no matter what strength of ignition is used. There is also persuasive evidence that a lower limit exists, below which the MEC remains constant. Figure 4 shows the results for pyrite. The MEC is larger for larger particles; the upper limit for explosible particle sizes was not reached. The upturn for the lowest particle size was quite unexpected. Perhaps, it may indicate that a significant amount of oxidation has occurred on these particles, so that the actual amount of pyrite present was much smaller than the nominal amount dispersed. The reason why this would not cause any effect on the other parameters was that in those tests an excessive amount of pyrite dust was used, so that the presence of some inert material would not significantly affect the results.

The standard ignitor (a pyrotechnic type manufactured by Sobbe in Germany) used in the 20-L vessel has an energy of 5000 J. The same type of ignitor is available in several lower strengths. Thus, it is possible to bracket the minimum ignition energy (MIE). As would be expected, the finer the pyrite particles, the lower the MIE (Figure 5). The MIE decreases by more than an order of magnitude in the range of particle sizes examined.

Since oxygen is a necessary ingredient for dust explosions, replacing all or part of the oxygen by an inert gas will create an inert atmosphere in which explosions cannot occur. This method is widely used in industry. The minimum oxygen concentration (MOC) is the key parameter to be measured, which was done for three size fractions of pyrite dust. To determine the MOC, $P_{max}$ was measured as a function of oxygen concentration (Figure 6). In order to have a "true" explosion, the $P_{max}$ must be greater than 100 kPa. Thus, for particles of mean diameter 180 $\mu$m, the MOC is about 16%. For 95 $\mu$m particles, the MOC is about 12%. It appears that reducing the size even further does not further decrease the MOC.

In coal mines, limestone dust is routinely used for inerting the coal dust. In Canadian mines, the total amount of incombustibles (limestone plus moisture and ash in the coal) must be greater than 75% of the coal/limestone dust mixture. To determine the amount of limestone required for use with sulphide ores, mixtures of two pyrite fractions with various amounts of very fine fractions of $CaCO_3$ were tested in the 20-L vessel. The results (see Fig. 7) show that only 20% is required for particles of 95 $\mu$m; a larger amount, about 32% is required for the very fine pyrite powder. If a coarser grade of limestone were used, then a larger percentage would be required. Also, if the limestone and pyrite dust were not intimately mixed as in these tests, more limestone would be required to compensate for the regions in which there was less limestone. On the other hand, ores containing less than 100% pyrite would require a smaller percentage of limestone.

Explosions of both pyrite and pyrrhotite can generate red dust (hematite) or black dust (magnetite), or a combination. In laboratory tests, red dust predominates when the explosion is weaker (lower concentration of dust or oxygen) and black dust predominates when the explosion is stronger. The cause for the difference is the thermodynamics of the system: the net energy release is slightly greater for the hematite reaction, which means that high temperatures (stronger explosions) would favour the magnetite reaction.

| | $\Delta H$ |
|---|---|
| $FeS_2 + 2¾\ O_2 \rightarrow ½\ Fe_2O_3$ (hematite) $+ 2\ SO_2$ | -829 kJ $mol^{-1}$ |
| $FeS + 2⅔\ O_2 \rightarrow ⅓\ Fe_3O_4$ (magnetite) $+ 2\ SO_2$ | -789 kJ $mol^{-1}$ |

**Conclusions**

The most important information that laboratory explosion testing can reveal is whether or not a particular dust is explosible. This may be to explain an explosion or to decide if preventative measurements are required. However, it is of particular importance that suitable apparatus be used for that purpose, otherwise a false sense of security may be obtained.

Secondly, laboratory explosion tests can rank dusts according to their relative hazard. Once the parameters contributing to the hazard have been identified, the relative hazard can be determined from the analysis of the ore and further explosibility testing need not be carried out.

Thirdly, laboratory explosion testing can assess some methods of mitigation, for example, the amount of inert gas required to prevent the possibility of explosion, or the percentage of noncombustible dust that must be added to an explosible dust to inert it. This work would have to be followed by mine-scale trials.

**References**

1. Gardner, E.D. and Stein, E. *Explosibility of sulphide dusts in metal mines*, U.S. Bureau of Mines Report of Investigations Serial 2863, 1928.

2. Montgomery, W.J., Can. Min. Met. Bull., 1962, pp. 765-767.

Fig.1. Relative Explosibility of Sulphide Ore Dusts

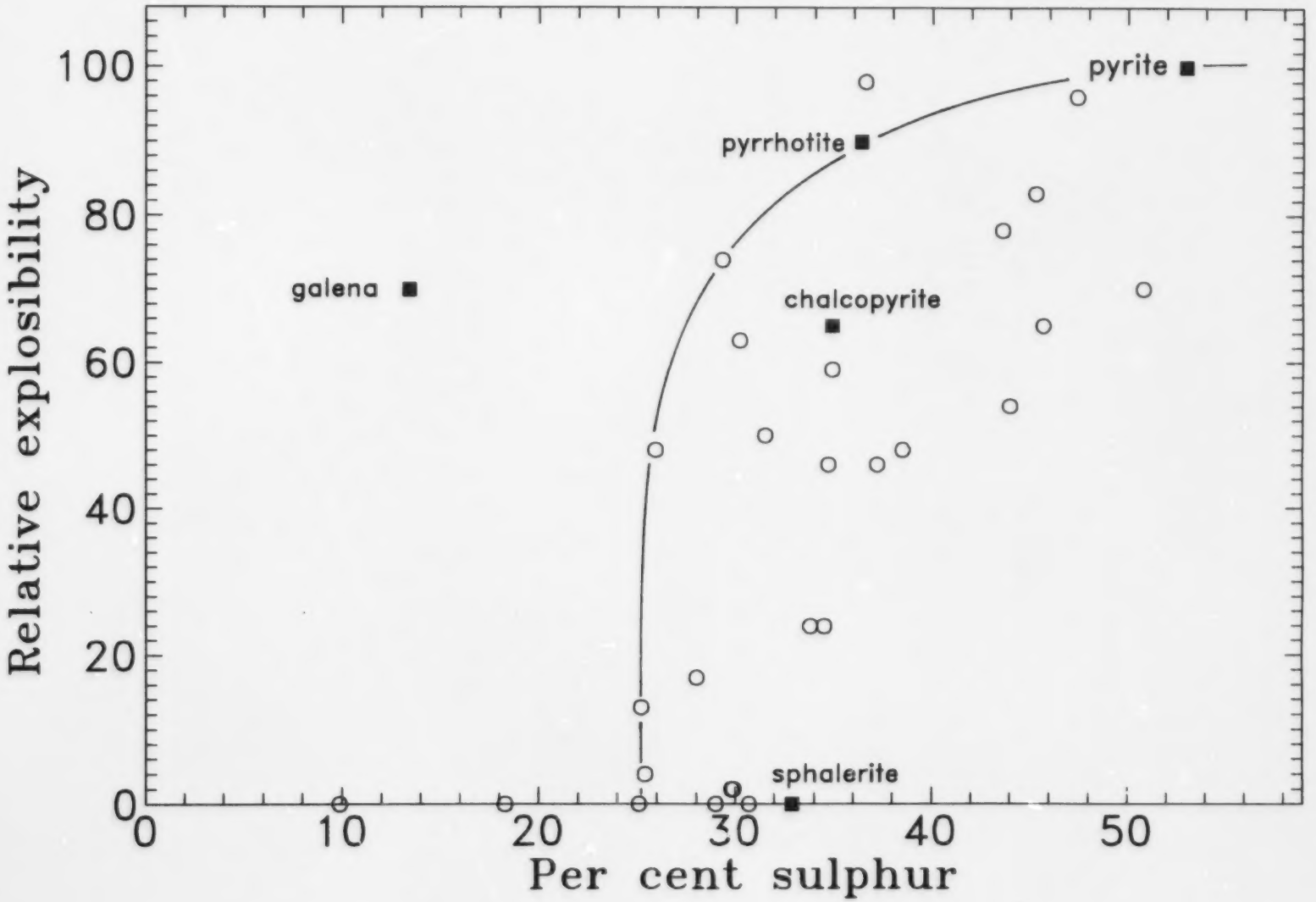

Fig.2. Explosion Pressure of Pyrite vs. Particle Diameter

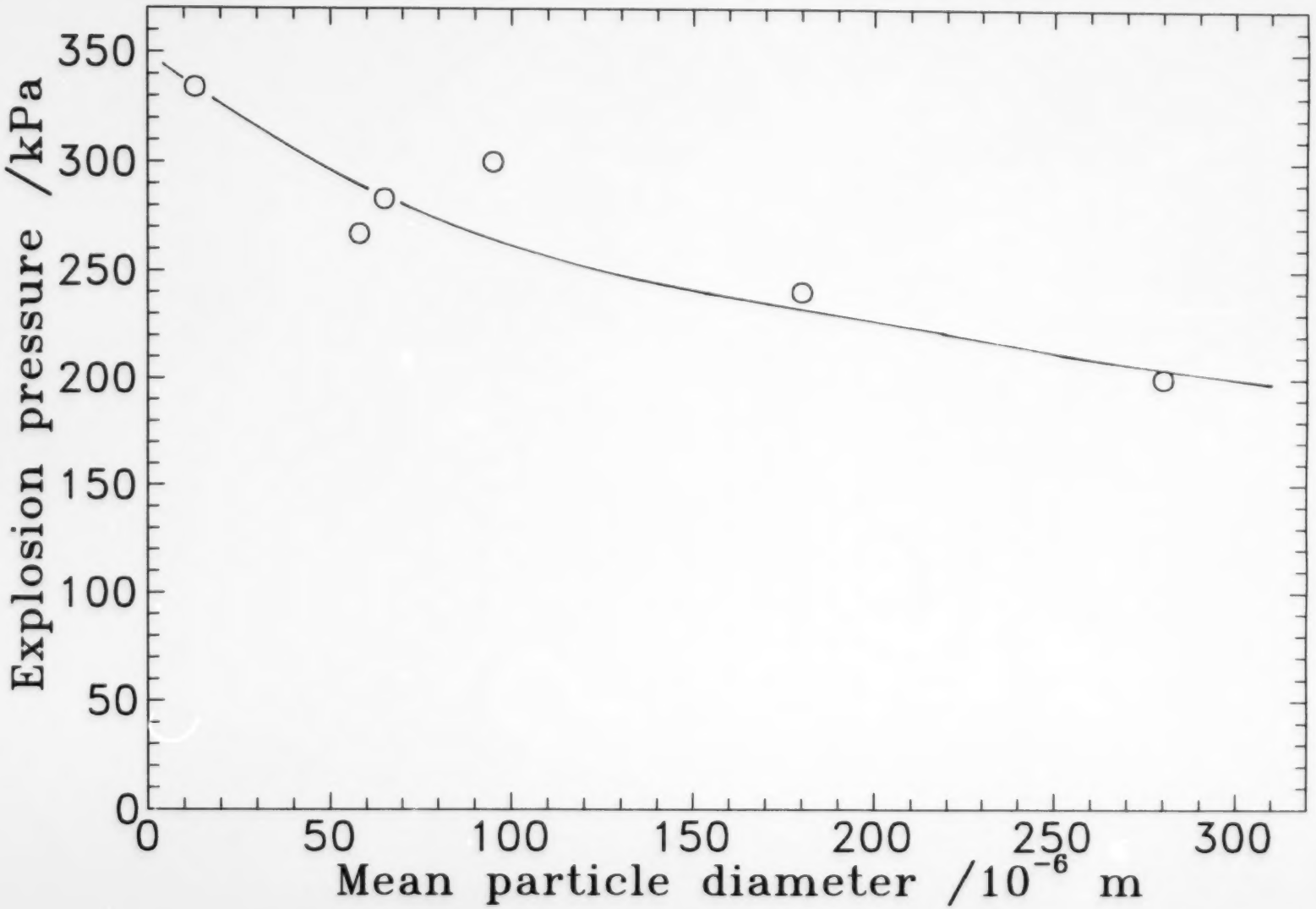

Fig.3. Rate of Pressure Rise of Pyrite vs. Particle Diameter

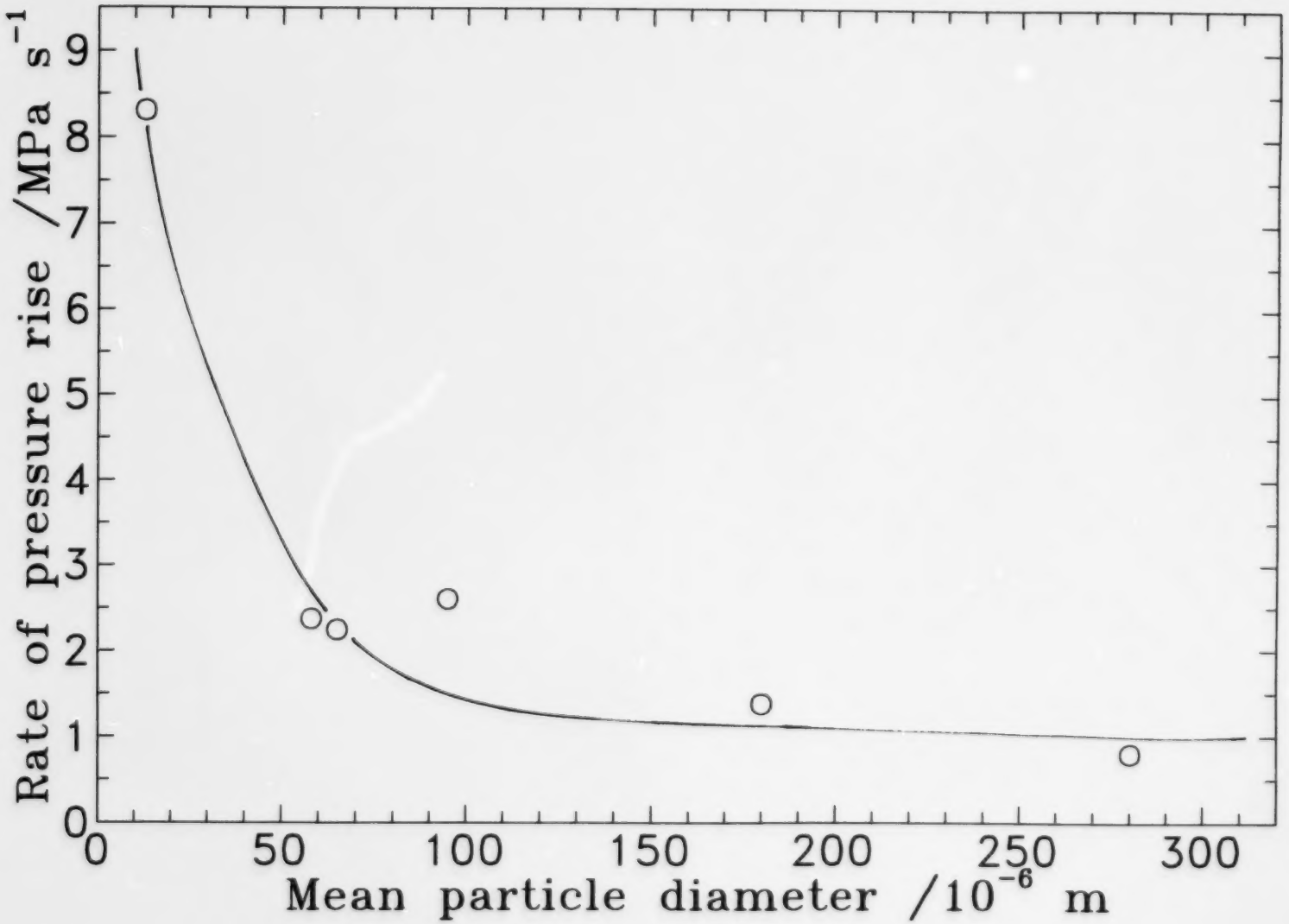

Fig.4. Minimum Explosible Concentration of Pyrite vs. Particle Diameter

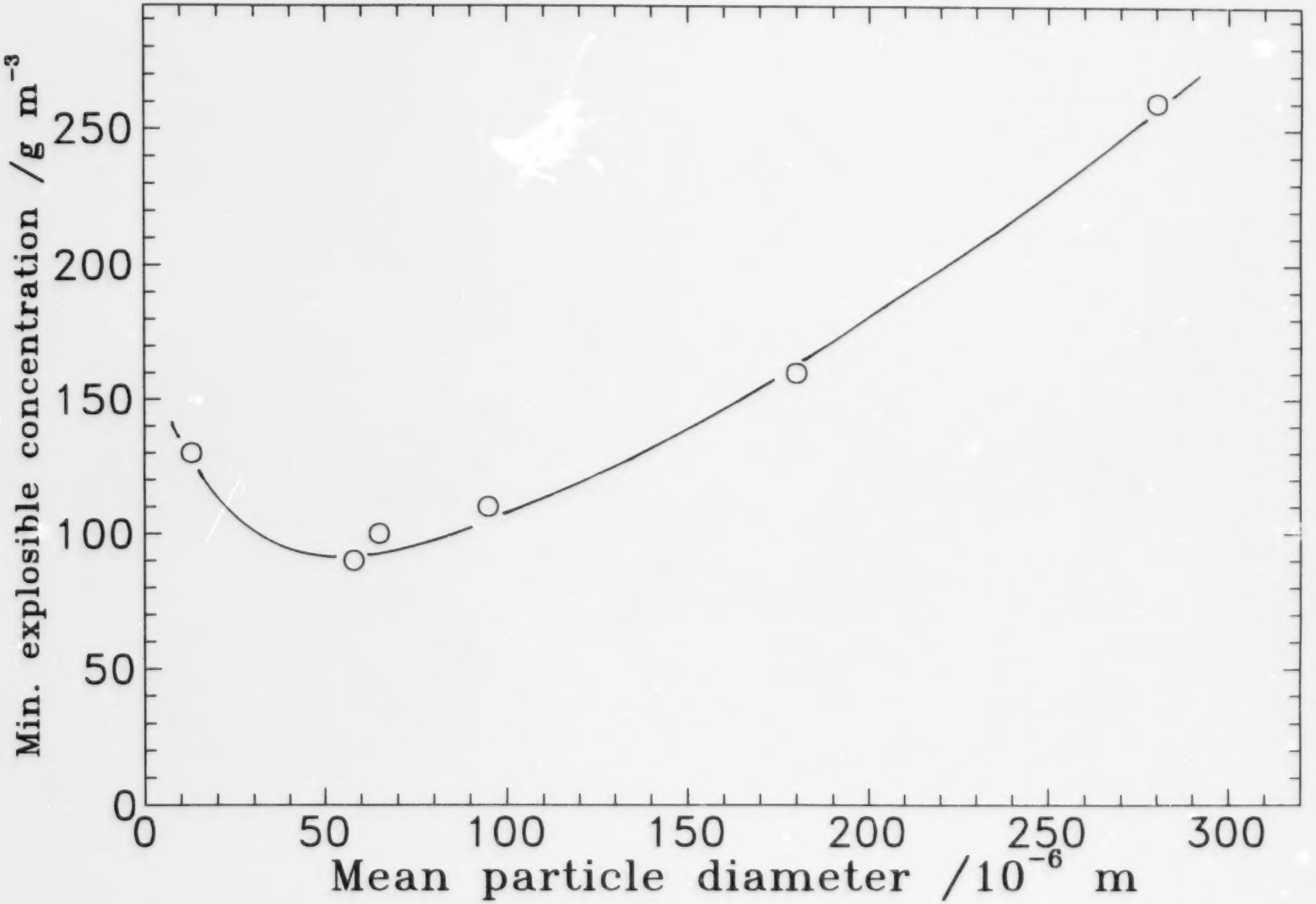

Fig.5. Minimum Ignition Energy of Pyrite vs. Particle Diameter

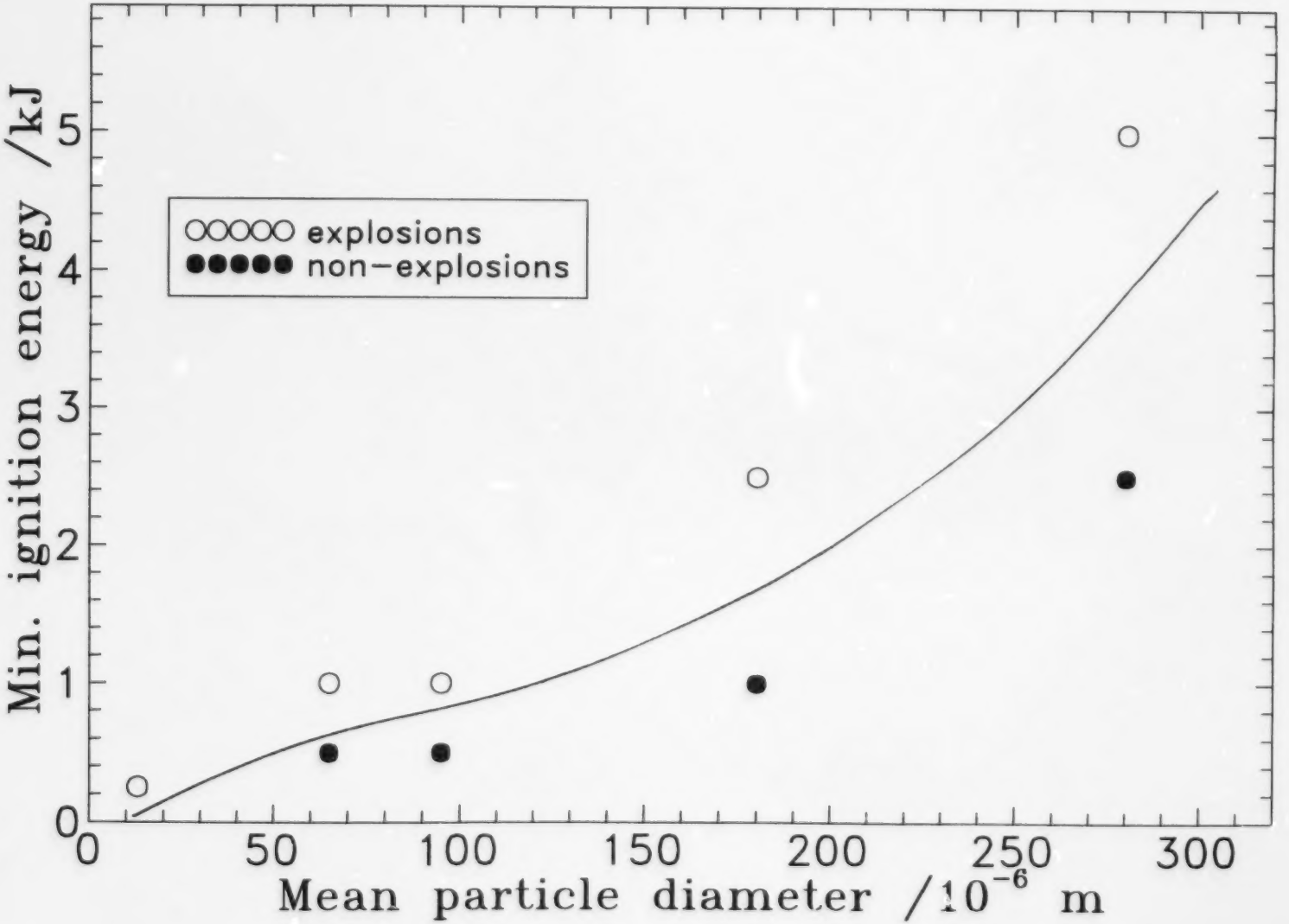

Fig.6. Maximum Explosion Pressure of Pyrite vs. $O_2$ Concentration

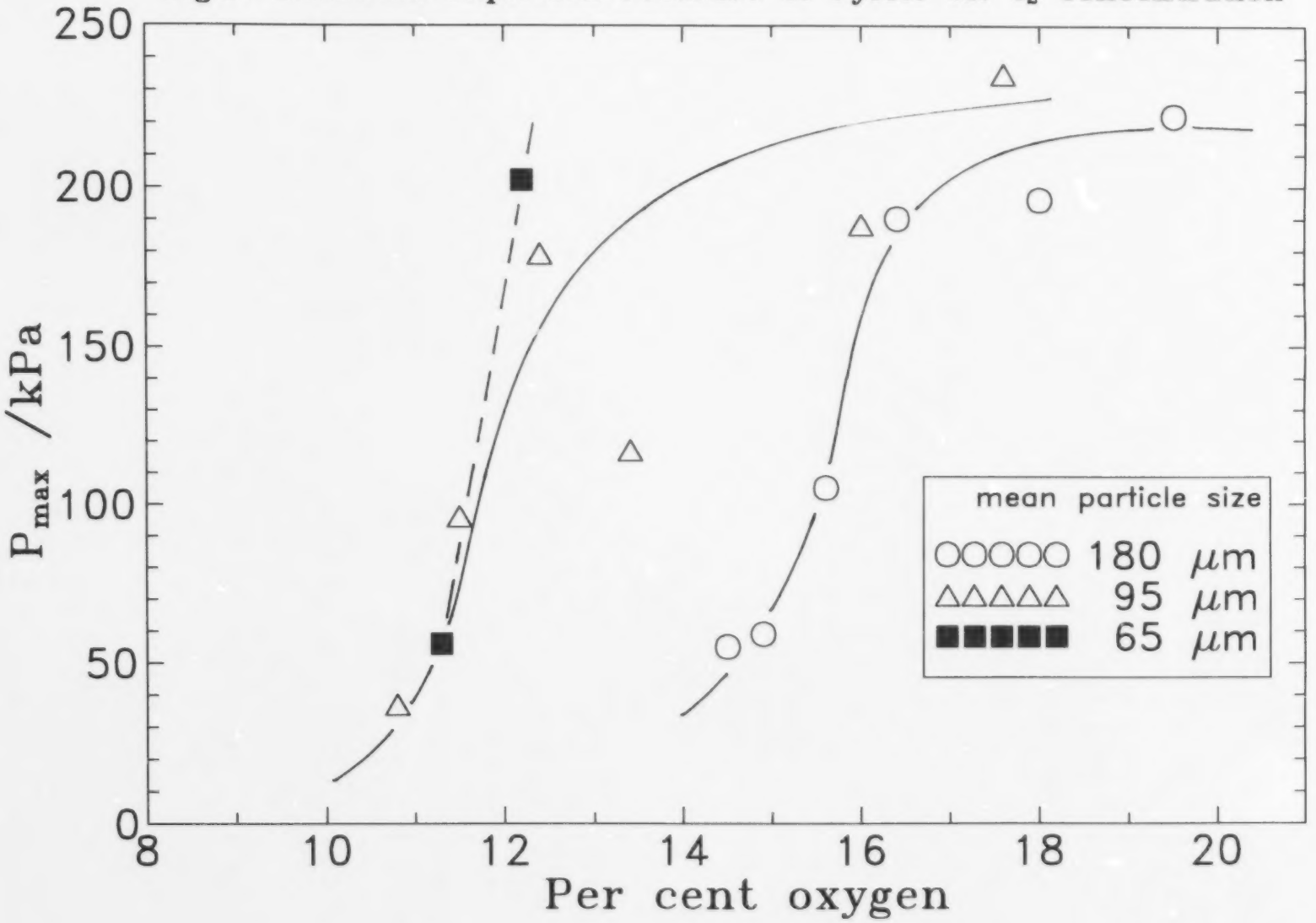

Fig.7. Effect of Inerting with Calcium Carbonate